

ZJAWISKA KRASOWE
WE WSCHODNIEJ SYBERII
(Karst Phenomena in Eastern Siberia)

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KARST PHENOMENA IN EASTERN SIBERIA

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In the southern part of Eastern Siberia, within what is called the „Irkutsk Amphitheatre”, karsting has developed in two regions: on the Siberian Platform, and in the mountains of the Eastern Sayan Ridge and in Chamar-Daban which together encircle the Platform from the south (fig. 1). The basic rock formations on the Platform where karsting processes developed are: limestones, dolomites, gypsum and anhydrite rocks of the Lower and Middle Cambrian (of 350 to 550 m thickness); in the mountains they are: Precambrian marbles and dolomites (elongated zones a few kilometers wide, intruded into crystalline rocks). The soluble rock formations occupy wide areas, some 350 000 sq. km. which constitute about 30% of the whole territory in question. Karsting proceeds here under the extreme conditions of a continental climate (figs. 2, 3) in a zone of long-term permafrost.

The author's aim was to classify, both genetically and by age, the local karst forms encountered, using as basis previous studies of an engineering and geological character made by local scientists as well as his own observations made in 1964. Further, the author made an attempt of determining the intensity of contemporaneous denudation.

In the southern part of the Siberian Platform (300—600 m a.s.l.) Karst is developed in two zones: a central, and a peripheral zone, respectively (fig. 4). The central zone consists of the Angara valley and the mouths of some of its larger tributaries, together with their short lateral valleys, while the peripheral zone comprises the middle and upper reaches of the large Angara tributaries, and areas lacking surface drainage. Well developed forms of surface karst can be observed upon the Platform; the largest of these forms is what in Russian is called „suchodol”, constituting a valley of some 50 or so kilometers' length (fig. 6). Within this kind of macroform are situated so-called „drainageless” depressions (karst hollows each of a few sq. km surface), often situated where several suchodols meet (photo 1). Usually such karst hollows are drained subterraneously by horizontally extending caves, the longest of which is known as the Balaganska Cave, of 1200 m length (fig. 7). Some of these hollows contain lakes. Mesoforms (sinkholes, „uvalas” and blind valleys) are very numerous here; mostly they are the result of the collapse of cave roofs. Forms of this type are found in greatest numbers in the suchodol slopes and between karst hollows (figs. 9, 18, photos 1, 2). Karst valleys also occur upon the flat Platform surface, between the suchodols; among them are valleys which pass into karst sinks some 50 or more meters deep. Among the numerous additional land forms for which the karst terminology knows no suitable terms, worth mentioning are pseudo-bugrove areas and travertine mounds. The former occur on terraces of the Angara and on the terraces of the transitory rivers (here alluvia overlie soluble rock formations) and these surfaces contain a large number of karst cavings developed due to infiltration of chemically active transitory flow. The latter, that is, travertine mounds are found in the peripheral regions; they are several meters high and

in their interior CaCO_3 is being currently deposited by the strongly mineralized waters penetrating from surface flow over the Platform (figs. 15, 16).

The Karst of the Siberian Platform is mostly alimented by allochthonic waters arriving from the adjoining mountain regions (transitory waters). There is but little autochthonic water, in view of the scarcity of atmospheric precipitation (from 250 to 500 mm annually). Infiltration of allochthonic water takes place in the boundary zone with the Platform and in the wide valleys carrying transitory water flow. These waters belong to the $\text{HCO}_3^- \text{Ca}^{++} \text{Mg}^{++}$ group; their principal feature is a low grade of mineralization and a high chemical activity (table. 1, figs. 17, 27, 34). At variance with them, the autochthonic waters are very strongly mineralized, and due to this they are chemically little active, being near their limit of saturation.

Most of the water of the transitory rivers which infiltrated along the boundary of the Platform does not reappear on the surface until the bottom of the Angara valley, which constitutes the denudation base for this entire area. This is also the reason, why frequently dry caves are encountered below the floors of higher-lying valleys. The karst springs yield here an ample flow of the order of a few to a dozen cu. m/sec. Part of the subterranean flow also appears on the surface where non-karsted rock formations of the Upper Cambrian and the Jurassic are exposed, or in deeply incised karst hollows. It has been ascertained, that the zones of dewatering tally with the line how the suchodols run.

Karsting in the mountains is characterized by a paucity of macro- and mesoforms; they occur usually in relief form on older planation surfaces. On the other hand, the underground hydrography is well developed. Worth mentioning as a characteristic feature are well advanced zones of karst caves ("ponores") and springs and, particularly, underground flow capture between neighbouring valleys. Valley sections built of permeable rocks are drained periodically (table 3). In particular the author discusses the characteristic of the karst hydrography of the Slyudyanka and the Pochabich valleys in Chamar-Daban (fig. 20, photo 3) and of the Kyngarga valley in the Tunkin Alps (figs. 24, 25). Here the karst waters are weakly mineralized and chemically little active (fig. 22, table. 1).

The author made an attempt of determining quantitatively the rate of karst denudation in Eastern Siberia; for this he applied his own hydrometric method which he had developed and verified in karst areas occurring in Poland. This method is based on the Equation:

$$D = 12.6 \frac{T \cdot Q}{P}$$

$$\text{or } D = 0.0126 T \cdot V$$

when: assuming V to equal $\frac{Q}{P} \cdot 1000$,

D — chemical denudation in cu. m/sq. km/year, or in mm/sq. km /1000 years,

T — content of soluble salts in mg/litre,

Q — runoff in cu. m/sec,

V — unit flow in litre/sec/sq. km,

P — area of examined drainage basin, in sq. km.

This interdependence can also be shown graphically (see fig. 26).

The individual terms involved in the above formulae have been interpreted in detail by a great number of measurements made by both local scientists and by the author himself. These studies contributed, apart from other factors, to the determination of the changes which during the annual cycle occur in water mineralization (table 1, figs. 32, 33), of the thermal conditions and the yields of the



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karst springs (figs. 12, 13), and of the chemical activity of the different waters (table 1, figs. 17, 27, 34).

The chemical denudation caused by karsting has been determined for 5 areas within the Platform and the mountains (table 7, figs. 23, 26). In this the author took into account not only the carbonate and sulphate content of the water, but also the sum of all salts carried off from the karst region examined. The denudation values were found to be lowest on the Platform where the area is alimented by autochthonic waters (the Unga valley with 8 cu. m/sq.km/year), and highest in the mountains (Chamar-Daban with 61 cu.m), as well as on the Platform where transitory water infiltrates (the Osa valley with 20 cu. m/sq.km/year). Further, the author calculated the overall chemical denudation (the total quantity of salts carried off from soluble and insoluble rocks) for the Angara drainage basin and for 2 of its larger tributaries. The different values found for this denudation are presented in figs. 29 and 30.

In calculating the chemical denudation the author also took into account 1) the content of salts derived from atmospheric precipitation (tabl. 5) and 2) the actual subterranean drainage basin which in karst regions is by no means identical with topographical conditions. Moreover, the author attempted to compute the complete denudation from the Angara drainage basin (Balagansk), taking also into account the bed-load dragged along the river bottom and the material suspended in the water. The mean long-term values, calculated for the total drainage basin of 655 000 sq. km, are 34 cu. m/sq.km/year; chemical denudation accounts for 10 to 20% of this value.

For purposes of comparison the author also calculated the chemical denudation on the basis of Corbel's climatic method ($d = 4 ET/100$); in areas well examined as to their climatic conditions he obtained similar values (table 6).

Conclusions

On the basis of the data presented above the author formulates the following conclusions:

1. The Karst of the Siberian Platform has developed during at least three successive periods: the Middle Cambrian, the Upper Paleozoic, and the time from the Jurassic until today. Of decisive influence upon the karsting processes has been, apart from structure and climate, the situation of the land, which facilitated the infiltration of large quantities of chemically active water arriving from the mountains. The valley floors of the big transitory streams, principally the floor the Angara, constitute the base of denudation; apart from this, these rivers also affect the rate of contemporaneous degradation. In consequence of these conditions, a remarkable karst relief came into existence, typical of platforms built of soluble rocks and developed in a zone of long-term permafrost. This relief has no correlated form in areas of classical karsting nor in other karst types. For this reason the author suggests to distinguish this relief by a separate term like: Siberian karst type.

2. In the Karst zone of Eastern Siberia the intensity of contemporaneous denudation is not conformable with the actual shape of the karst relief. The mountains where the intensity of denudation is highest, show a scarcity of karst forms, while on the Platform with its negligible denudation macro- and mesoforms appear well developed. This can be explained by the differences in the periods in which the individual karst areas developed. In the mountains the limestones were not exposed on the ground surface until the Tertiary and the Quaternary, while on the Platform karsting proceeded as early as during the Lower Paleozoic.

3. The difference in chemical denudation between the mountain area and the Platform must be mainly ascribed to two agencies: the amount of water flow, and the degree of its mineralization. In spite of a high salt content, denudation on the Platform is slight because precipitation is low; conditions are the opposite in the mountains. This interrelation is confirmed by the rate of denudation observed during the year: removal of material is most intensive during the most humid months, i.e. in summer and spring, although these are the shortest seasons of the year and are associated with the lowest degree of mineralization of the water.

4. The influence of long-term permafrost upon karsting processes is but slight in Eastern Siberia. It was found, that karsted areas are mostly devoid of permafrost — a fact facilitating the unobstructed circulation of underground waters. All the same, permafrost affects karsting indirectly, because it supplies plenty of water during snowmelt and is apt to form local bases of denudation.

5. In the Eastern Siberian Karst a considerable intensity of karst denudation has been observed, oscillating between 0.01 and 0.06 mm/year. Still, these values are at the most half of what they are in karst areas of Europe situated in similar geographical latitudes.

6. The karst waters of the mountain areas and the allochthonic waters on the Platform are strongly aggressive and liable to cause further chemical denudation. This fact constitutes a marked danger to hydraulic structures and other kinds of economic activities along the Angara banks.

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